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TECHNICAL MEMORANDUM

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EFFECTS OF GROSS LOAD AND VARIOUS BOW MODIFICATIONS ON THE HYDRODYNAMIC CHARACTERISTICS OF A HIGH-SUBSONIC MINE-LAYING SEAPLANE

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TECHNICAL MEMORANDUM X-71

EFFECTS OF GROSS LOAD AND VARIOUS BOW MODIFICATIONS ON THE HYDRODYNAMIC CHARACTERISTICS OF A HIGH-SUBSONIC MINE-LAYING SEAPLANE

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SUMMARY

An investigation of the hydrodynamic characteristics of a high-subsonic mine-laying seaplane and three bow modifications has been made in Langley tank no. 1. The bow modifications consisted of two 10-foot extensions in forebody length and one 20-foot extension. The hydrodynamic qualities investigated included longitudinal stability during take-off, bow-spray characteristics in smooth water and in oncoming waves through hump speed, determination of resistance both in smooth and rough water, and behavior during taxiing in waves.

Results obtained indicate that the basic configuration has marginal longitudinal stability characteristics because of a severely restricted trim range for completely stable take-offs. Increase in bow length eliminates a false hump in the smooth-water resistance curve of the basic configuration. The effects of increase in bow length on the true hump resistance are small. For operation in rough water, the basic configuration is limited to small waves by excessive spray in the region of the engine alternate air intakes. Increases in bow length progressively raise the spray boundary thus defined to higher wave heights. The effects of gross weight and the manner of increasing bow length on the spray boundary are small. The hump resistance in rough water increases with wave height but is relatively unaffected by bow length.

INTRODUCTION

Investigations of the hydrodynamic characteristics of the basic design of the seaplane have indicated that it had marginal rough-water bow-spray characteristics at the normal gross load of 160,000 pounds and possible longitudinal stability problems at intermediate trims. Inasmuch as the proposed prototype of this seaplane, which has increased power, is intended to operate at heavier gross loads, an investigation of the stability and spray characteristics at gross loads up to at least 220,000 pounds was made and the influence of various bow modifications on the hydrodynamic characteristics of the prototype model have been evaluated. The basic prototype model and the three bow modifications were supplied by the manufacturer.

The hydrodynamic qualities investigated included longitudinal stability during take-off, bow-spray characteristics in smooth water and in oncoming waves through hump speed, determination of resistance both in smooth and rough water, and behavior during taxiing in waves.

SYMBOLS

V horizontal speed, knots

Δ_0 gross load, lb

δ_e elevator deflection relative to stabilizer, deg

δ_f flap deflection, deg

δ_s horizontal stabilizer deflection relative to forebody keel at step, deg

τ trim (angle between forebody keel at step and horizontal), deg

DESCRIPTION OF MODELS

The general arrangement of the basic configuration is shown in figure 1. Photographs of the 1/13.33-scale dynamic model of the basic configuration are shown in figure 2. The model was constructed mainly of fiber glass and plastic. The basic model was modified by the manufacturer to correspond to the prototype. The wing tips were raised to give more clearance at the increased gross weights by changing the wing dihedral to 1.5°. The nacelles were canted 3° to keep the jet exhaust away from the hull. The model was unpowered throughout these tests.

When balanced about the 28.8-percent mean aerodynamic chord, the pitching moment of inertia of the ballasted model was 8.8 slug-ft^2, corresponding to a full-scale moment of inertia of 3.7×10^6 slug-ft^2;

this value is approximately 100 percent over that of the basic seaplane at the gross load of 160,000 pounds.

Hull lines for the basic and alternate forebodies are shown in figure 3. The bow of the basic model was made removable at hull station 393 to allow for attachment of the bow modifications at this point. The following configurations were tested:

Langley tank model 364: This was the basic model. The bow of this model is considered to be a low-chine bow.

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Langley tank model 364A: This model incorporated a faired 10-foot bow extension, the general lines of which can be seen in figure 3. This bow is considered to be an intermediate-chine bow.

Langley tank model 364B: This model incorporated a faired 20-foot bow extension, the general lines of which also can be seen in figure 3. This bow is considered to be a high-chine bow.

Langley tank model 364C: This configuration incorporated the basic bow, together with a 10-foot linear spacer. The 10-foot linear spacer is the simplest way to extend the bow length of the full-scale airplane from the manufacturer's point of view. Use of the linear spacer necessitated a slight refairing of the forebody bottom from station 393 to the step. (See fig. 3.) The resulting lines are not faired at the junction of the spacer and station 393 so that a slight, although almost imperceptible, knuckle is introduced at this point. The general lines of this bow extension can be seen in figure 3. This bow also is considered to be a low-chine bow.

APPARATUS AND PROCEDURES

The tests were conducted in Langley tank no. 1. The apparatus and procedures were generally the same as those used for the tests described in reference 1. The model was free to trim about the center of gravity and was free to move vertically but was restrained in roll and yaw. In addition, for the rough-water investigation, the model had approximately 5 feet of fore-and-aft freedom with respect to the towing carriage. Initially, the model was balanced about 28.8-percent mean aerodynamic chord; however, in order to simulate the effect of thrust, a static-thrust moment equivalent to a full-scale thrust moment of 31,600 ft-lb was applied throughout the investigation (except as noted under longitudinal stability). This static-thrust moment had the effect of moving the center of gravity slightly forward of the 28.8-percent mean aerodynamic chord. The flaps were set at 0° for all tests except for the longitudinal stability and high-speed resistance tests of the basic configuration, for which the flaps were deflected to the take-off setting of 38°.

In general, data were obtained at gross loads corresponding to full-scale loads ranging from 160,000 pounds to 240,000 pounds. The trim limits of stability were determined by making a series of take-offs in calm water at a constant rate of acceleration of approximately 2.5 feet per second per second for a series of fixed tail settings. From plots of the variation of trim with speed, the trim limits, where porpoising appeared to start, were determined. The data for the 175,000-pound condition were obtained with an applied thrust moment. During the first run at 190,000 pounds with thrust moment, model damage resulted from high-speed low-trim directional instability. As a safety precaution, the remainder of the longitudinal stability investigation was conducted without the bow-down thrust moment. With the exception of changing the trim tracks for given tail settings, the limits should be essentially the same as though thrust moment was present. The bow-spray characteristics were determined from visual observations and from motion pictures of constant-speed and accelerated runs. In addition, still photographs were taken of the smooth-water spray. The resistance of the model was determined with a series of constant-speed runs. For the basic configuration, smooth-water resistance was determined to take-off speed. For the modified configurations resistance was determined to just beyond hump speed since the difference in bow length would not affect the high-speed resistance. Rough-water resistance also was measured to just beyond hump speed by the method described in reference 1. A load cell was attached to the front of the roller cage of the fore-and-aft gear. Long rubber strands were attached to the load cell with tension adjusted to keep the model free of the fore-and-aft stops during the test runs.

Rough-water behavior was determined from visual observations and motion-picture studies of all the runs in waves. Since at low speeds spray and behavior (motions in pitch and heave) are generally most critical in short waves, the current tests were conducted in the shortest reproducible waves that the tank no. 1 wavemaker was capable of generating for the selected wave heights. Tests therefore were made in wave lengths equivalent to full-scale lengths of 146, 160, 200, and 240 feet for the 2-, 4-, 6-, and 8-foot-high waves, respectively.

RESULTS AND DISCUSSION

The data obtained are presented as full-scale values.

Longitudinal Stability

The longitudinal stability characteristics were determined only for the basic configuration; however, it is felt they would be essentially the same for the other configurations. The variation of trim with speed, obtained during accelerated runs, is shown in figure 4 for several tail settings and gross loads corresponding to 175,000, 190,000, and 220,000 pounds.

Inspection of the trim tracks presented in figure 4 shows: (1) an upper trim limit of stability with porpoising amplitudes on the order of 5° encountered during high trim take-off; (2) a marked pitch-up at slightly lower trims due to afterbody suction forces that tend to trim the model into the upper limit and often induce erratic porpoising cycles that continue throughout the remainder of the take-off; (3) an intermediate trim range during which relatively stable take-offs can be made; however, in this region low-amplitude, nondivergent oscillations occur somewhat above the lower limit; and, (4) a lower trim limit of stability below which divergent instability occurs.

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The trim limits of stability and afterbody suction limits deduced from these runs are presented in figure 5 for the various loads investigated. With increase in load, the trim limits are shifted to somewhat higher trims and speeds so that the available stable trim range between the lower and upper limits remains essentially the same, regardless of load. The lower limit was not defined at speeds near take-off due to low-trim directional instability. The afterbody suction limits which have been previously mentioned and which are also presented in figure 5 result from afterbody suction forces due to the combination of shallow step depth and long afterbody length. In this instance flow leaving the step attaches to the afterbody with sufficient strength to overcome the aerodynamic moment and tends to trim the model into the upper limit. The ensuing erratic porpoising cycles are at times severe and pose somewhat of a take-off problem for this aircraft.

The longitudinal stability characteristics of the basic configuration must be classified as marginal because of the severe restriction in available trim range for completely stable take-offs. This restriction is attributed to the afterbody suction forces in the intermediate trim range and the low-amplitude oscillations occurring slightly above the lower limit.

Smooth-Water Spray

Photographs showing the severest spray conditions encountered during the smooth-water spray investigation are shown in figure 6 for the basic configuration and in figure 7 for the modified forebodies. The bow-spray characteristics of each of the modified configurations at the heaviest load investigated were superior to those of the basic configuration at any load down to a gross load of 160,000 pounds. None of the modified forebodies encountered any inlet spray whatsoever, whereas the inlets of the basic configuration were wetted at all loads in excess of 160,000 pounds.

Spray was thrown over the wings of the basic configuration at all loads in the speed range from approximately 27 to 43 knots. For the modified forebodies, spray over the wing was practically nonexistent. The underside of the wing generally was fairly heavily wetted for all configurations in the speed range from about 35 knots to 70 knots. Since the flaps are not generally deflected from the 0° position until higher speeds are reached, this spray is not considered to be critical.

Of the various forebody extensions, the 20-foot bow had the best spray characteristics. For the two 10-foot bow extensions, the spray characteristics were very similar; thus forebody length appears to be a more significant parameter than chine height or shape details in controlling bow spray.

Rough-Water Spray

Plots defining the rough-water bow-spray characteristics of the basic and modified configurations are presented in figures 8 and 9, respectively. These plots define the intensity of spray entering the inlets, flowing over the wing, and striking the flap area and underside of the wing during constant-speed and accelerated runs at speeds up to hump speed. On the basis of information obtained from the manufacturer concerning flight tests of the basic airplanes, the inlet spray appears to be most critical in that it interferes with the operation of the jet engines. The estimated operating limits of load and wave height were therefore determined on the basis of inlet spray only. The limits shown are "judgment" limits and are based on visual observations made during the test runs and from studies of motion pictures made of these runs by the engineer assigned to these tests by the manufacturer who was present during the tests and by the author.

When these limits were determined, consideration was given to the fact that alternate air intakes on top of the nacelles have been incorporated in the prototype. The spray was considered unacceptable when spray originating from the radome and sides above the chines heavily wetted the upper surfaces of the nacelles in the vicinity of the alternate intakes. The limits obtained with the various configurations have been presented in figure 10 for comparison. On the basis of such an analysis, the basic configuration cannot operate into oncoming 3-foot-high waves above a load of 175,000 pounds. During the tests of the basic configuration in 4-foot-high waves, the bow dug into practically every wave and great amounts of spray were thrown over the entire model and at times obscured most of it from view. The other configurations are restricted to seas on the order of 4 to 5 feet high for the 10- and 20-foot extensions, respectively.

Here again the 20-foot bow extension was best but the margin of superiority was not nearly as pronounced as in smooth water, since the radome became the primary source of the spray thrown into the alternate intakes. For the two 10-foot bow extensions, the spray characteristics again were similar.

Smooth-Water Resistance

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Curves showing the variation of smooth-water resistance for best trim and trim with speed for the basic configuration are shown in figure 11 for the various loads tested. These curves are compared in a summary plot in figure 12. With the basic model, a "false" hump in the resistance curve occurs at a speed slightly below that of the main hump. In calm or glassy water, the false hump resistance severely restricts operation at heavier loads. However, a slight disturbance of the surface of the water reduces the magnitude of the false hump very significantly, as will be shown in a later figure. At low speeds in the displacement range, the short basic bow is in general rather heavily wetted, with flow adhering to the sides of the bow in the vicinity of the radome. The heavy wetting holds down the trim and induces the high resistance of the false hump. The flow finally breaks clear at from 40 to 45 knots and causes a rapid increase in trim. With further increase in speed, the model passes from the displacement to the planing range, and there is an abrupt reduction in resistance.

Curves showing the variation of resistance for best trim and trim with speed for the extended bows are presented in figure 13. With the longer bows, in smooth water the forebodies are not as fully wetted as was the basic model. The delayed increase in trim as hump speed is approached is not nearly as severe and, as a result, the false hump is very greatly reduced; in the case of the two faired bow extensions, the false hump practically disappears.

Comparison curves showing the variation of hump resistance with gross load are presented in figure 14 for the various configurations. The effect of operation in disturbed water, which is the state generally occurring in nature, on the "false" hump of the basic model is shown here. At 190,000 pounds and 220,000 pounds the disturbed-water false humps of the basic model are reduced significantly so that they are on the order of magnitude of the main hump. Based on main-hump resistance, without corrections for full-scale friction or allowance for acceleration, it appears that a gross load of approximately 195,000 pounds is the smooth-water operating limit for the basic configuration, an available thrust of 56,000 pounds being assumed. The effect of the bow modifications on the main hump resistance appears to be favorable but relatively insignificant. The above-mentioned gross load limitations due to resistance determine the operating limits for this aircraft in smooth water since, with alternate air intakes, calm-water spray is not critical throughout the load range investigated.

Rough-Water Resistance

Curves showing the variation of resistance with speed through the hump during operation in waves are presented in figures 15 to 18 for the various configurations. In general, these curves are very similar to those obtained in smooth water, apart from the fact that the average resistance in waves is higher than that in smooth water. Because of the presence of the waves, the false hump did not appear in the resistance curve of the basic model (fig. 15).

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The rough-water resistance data are summarized in figure 19, where curves showing the variation of hump resistance with gross load and wave height are presented for all configurations. If corrections for the scale effects are neglected, the basic configuration can apparently operate into oncoming waves 2 feet high at loads between 190,000 and 200,000 pounds, but in 4-foot-high waves hump resistance exceeds available thrust at all loads tested. All the other configurations can operate successfully in 4-foot waves up to loads on the order of 195,000 pounds. Differences in resistance between the forebody modifications appear to be slight. In 6-foot-high waves the hump resistance of all configurations exceeded available thrust at all loads investigated. Since the prototype is to be equipped with alternate air intakes, it appears that operation of this aircraft, in small waves, as was the case in smooth water, is limited by resistance rather than spray. These limits are shown in figure 19. Some resistance data obtained during a previous investigation of a similar model also are presented in figure 19 and are shown to be in general agreement with those of the present investigation.

Behavior in Waves

For the relatively low speeds of the rough-water investigation, there was no evidence of directional instability. The longitudinal motions in pitch, however, were fairly severe when running in regular waves too high for the given bow length and load.

In general, the behavior (motions in pitch and heave) with the modified bows was substantially better than that of the basic model. Motions with the 20-foot bow were less than those with the two 10-foot bows but only by a small margin. The greatest gain seems to come from the first 10 feet of bow extension.

SUMMARY OF RESULTS

The results of an investigation into the hydrodynamic characteristics of a high-subsonic mine-laying seaplane and of three extended bow modifications in general indicate that:

1. The longitudinal stability characteristics of the basic configuration are marginal. Afterbody suction forces contribute to a pitch-up which results in erratic upper-limit porpoising. This porpoising, together with a low-amplitude, nondivergent oscillation occurring slightly above the lower limit, severely restricts the available trim range for completely stable take-offs.

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2. The operation of the basic configuration is limited to small waves because of high resistance and excessive spray in the region of the alternate air doors on the tops of the nacelles. Increases in bow length progressively move the spray and resistance boundaries thus defined to higher wave heights. The effects of gross weight and the manner of increasing the bow length on the spray boundary are small.

3. The longer bows eliminate a false hump in the smooth-water resistance curve of the basic configuration which is caused by suction flow and low trim. The effects on the true hump resistance are small. The hump resistance in rough water increases with wave height and is relatively unaffected by bow length.

4. In general, the overall behavior of the modified bows in pitch and heave is substantially superior to that of the basic bow. The 20-foot bow is only slightly superior to the two 10-foot bow extensions. The greatest gain appears to come from the first 10 feet of bow extension. Based on results obtained with the two 10-foot bows, it appears that, within the range of the present investigation, bow length is a more significant parameter than chine height in controlling behavior.

5. It should perhaps be noted that the gross weight limitations indicated by the model data do not apply directly to full-scale operation because of scale effects on resistance, uncertainties as to the effective thrust available, the need for reasonable excess thrust to accelerate through the hump region at the maximum weight, and so forth. The uncorrected data, however, do demonstrate the existence of limitations to be expected due to both gross weight and wave size.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., June 12, 1959.

REFERENCE

1. Parkinson, John B.: NACA Model Investigations of Seaplanes in Waves. NACA TN 3419, 1955.

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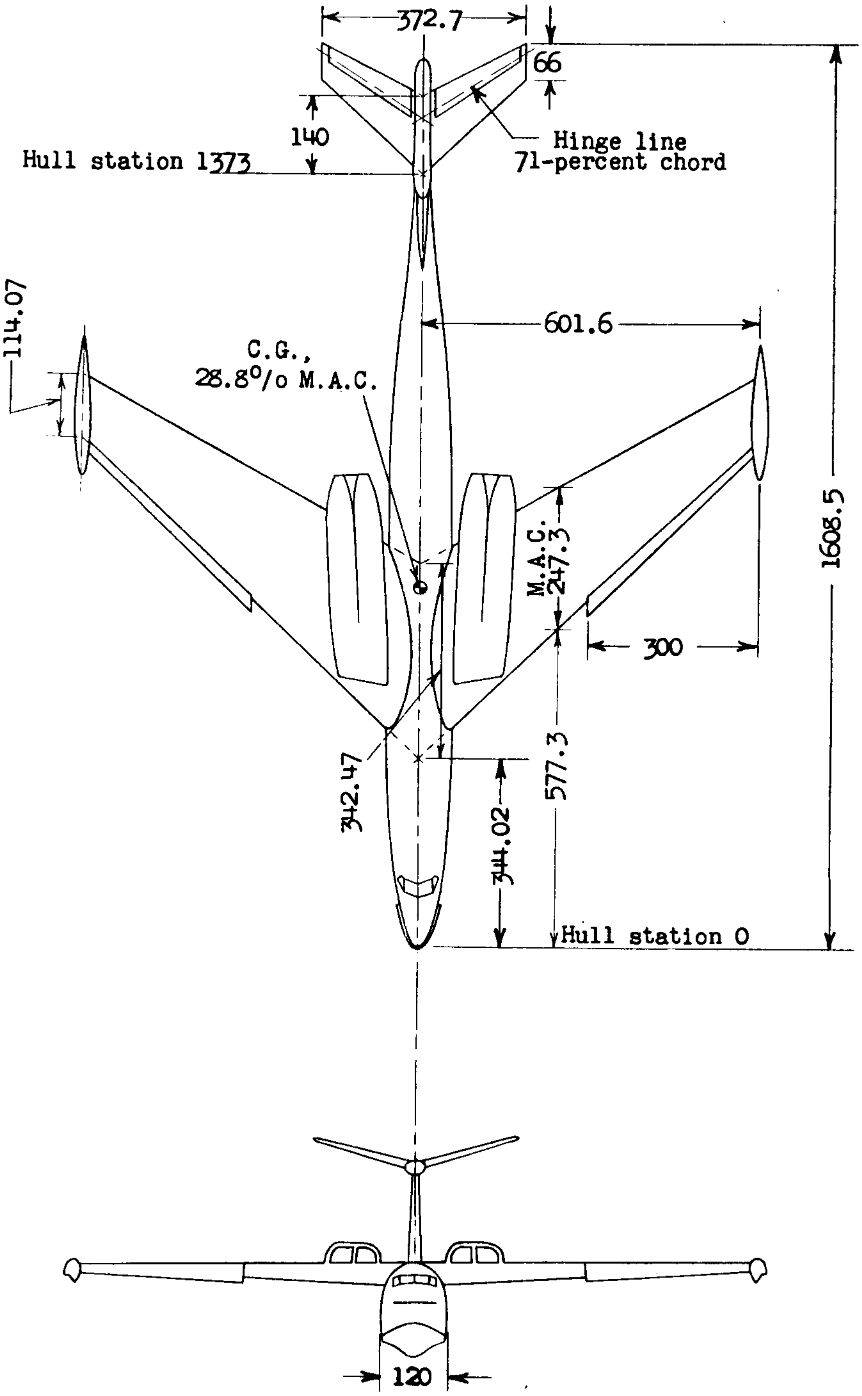
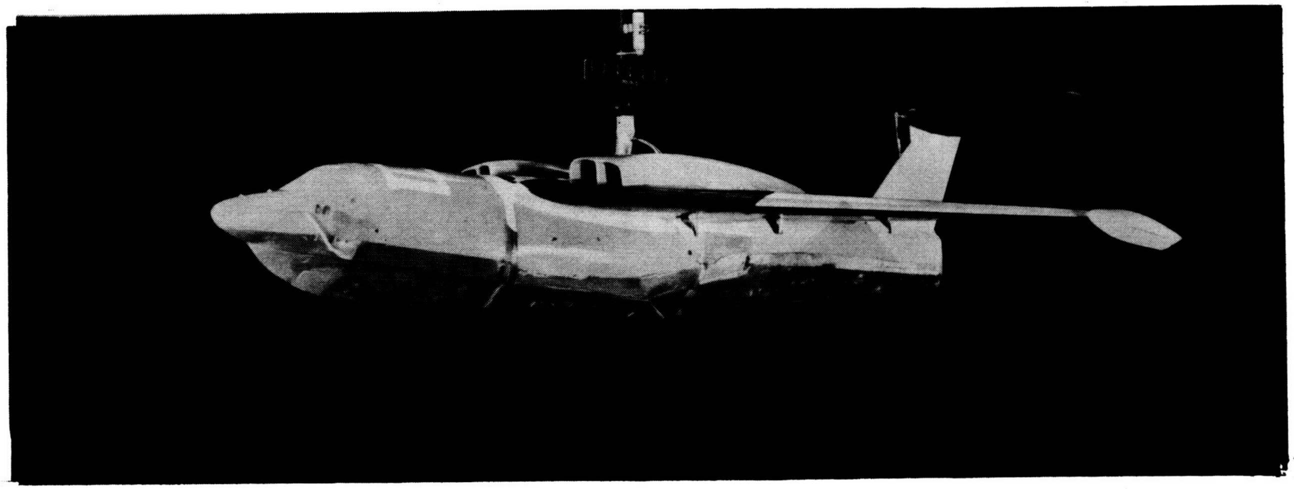


Figure 1.- General arrangement of the basic seaplane. Dimensions are in inches, full size.



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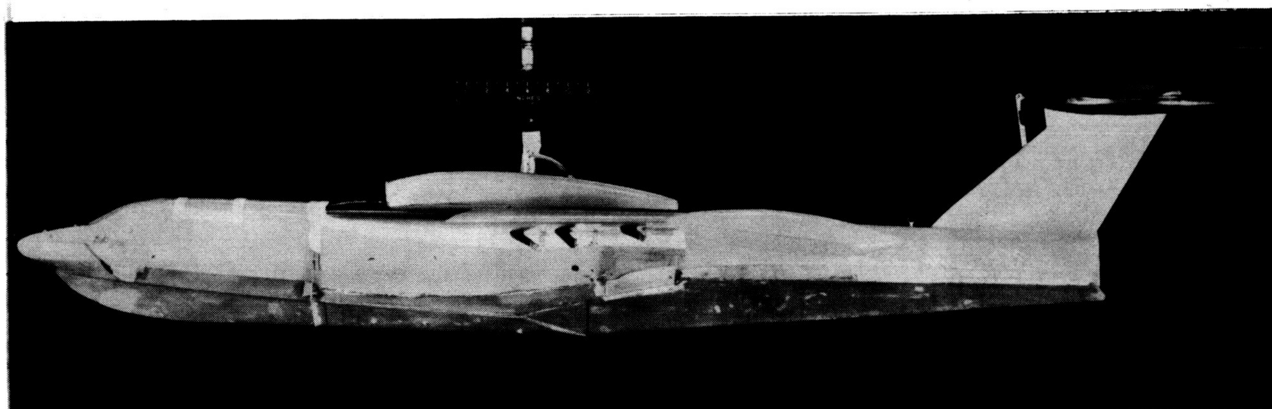

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Figure 2.- Photograph of basic configuration. Langley tank model 364.

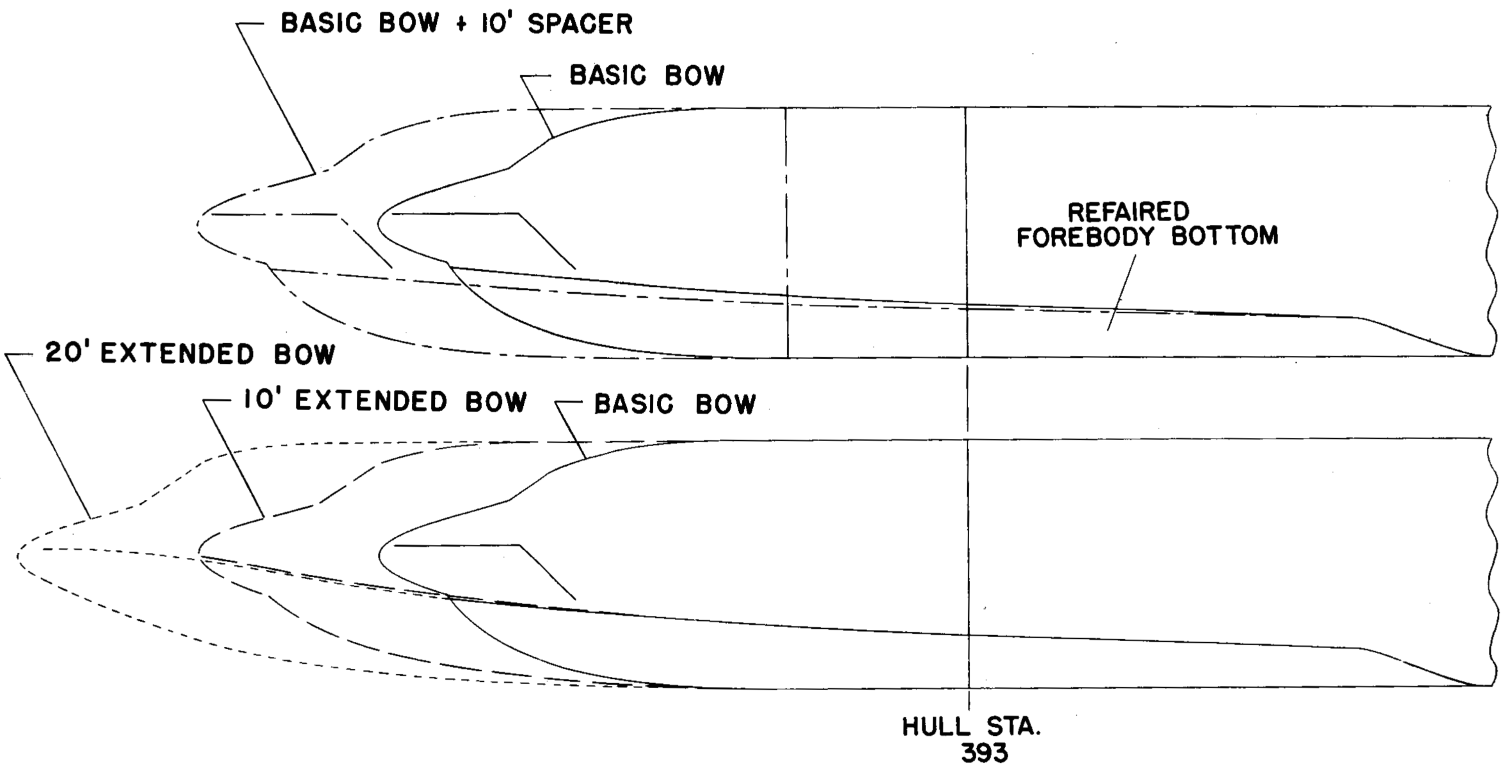
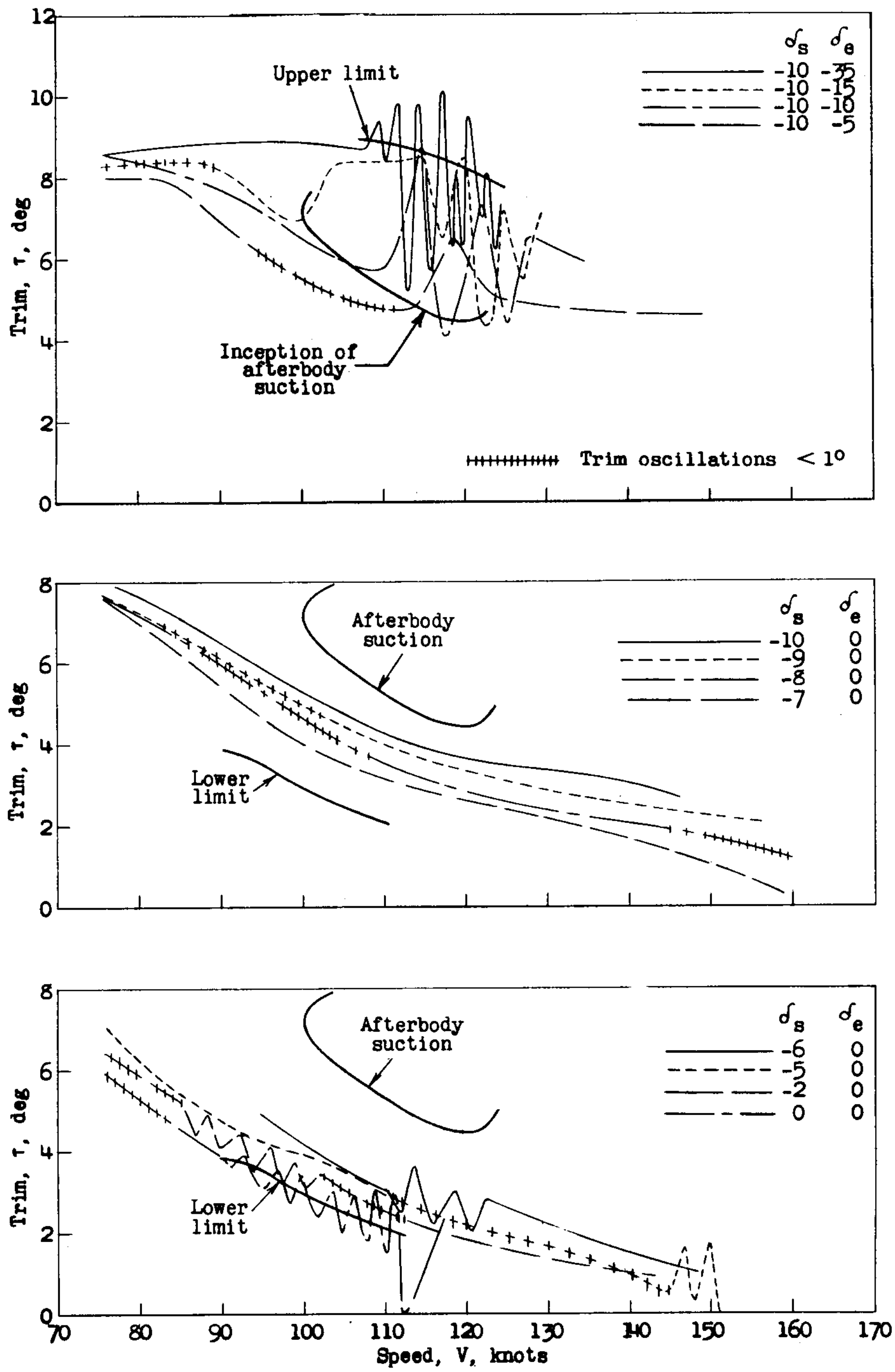
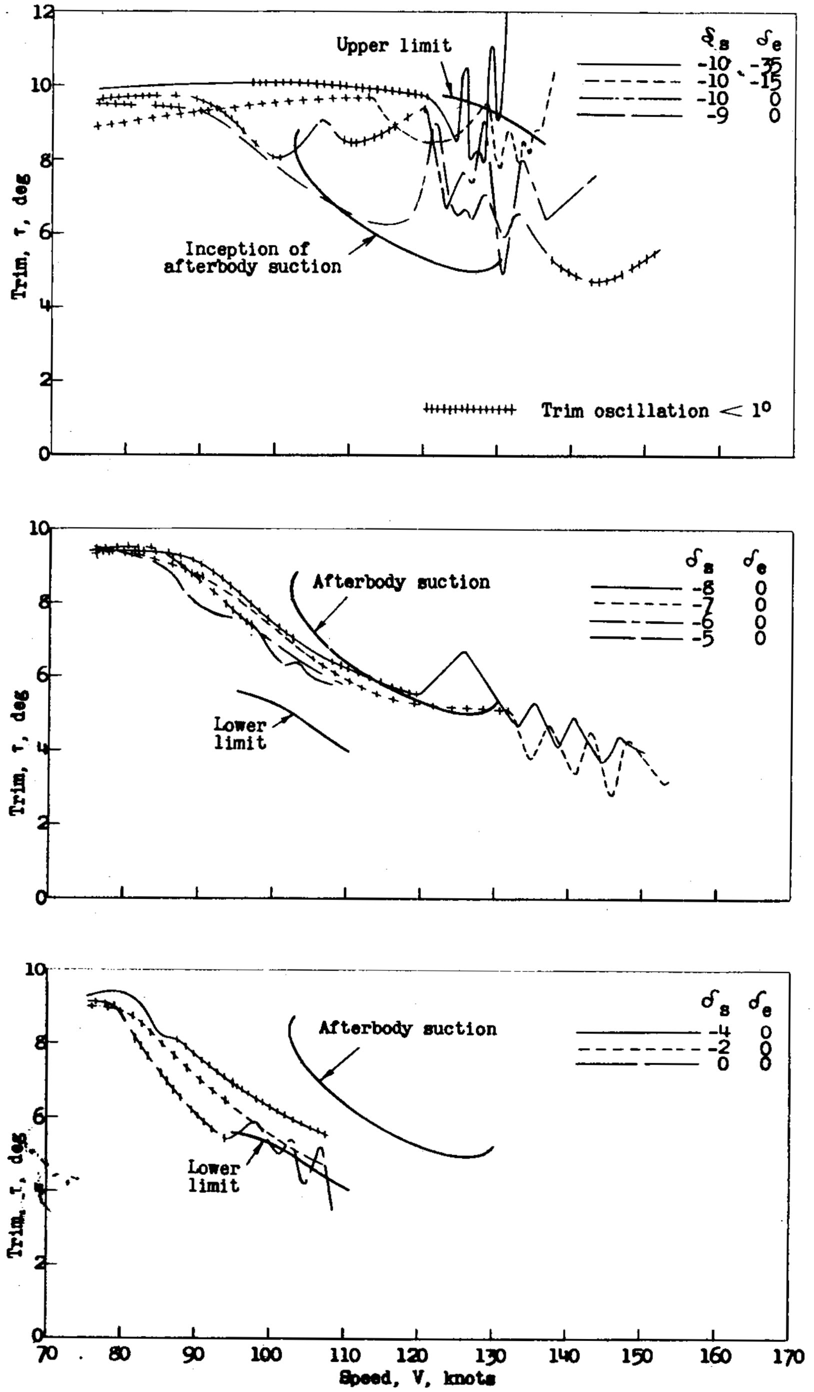


Figure 3.- Lines of basic and modified bows.



(a) Gross weight 175,000 pounds; with thrust moment.

Figure 4.- Smooth-water trim tracks. Basic configuration.



(b) Gross weight 190,000 pounds; no thrust moment.

Figure 4.- Continued.

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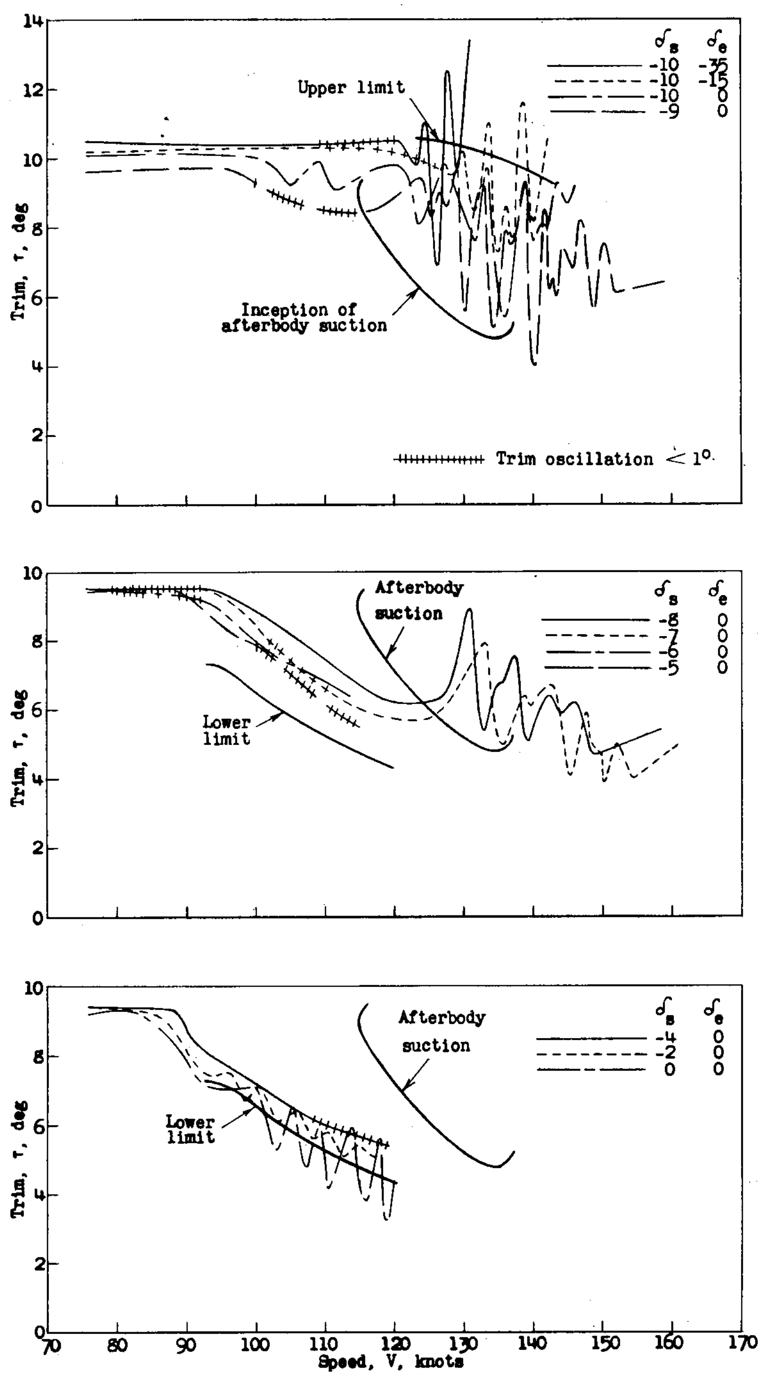

(c) Gross weight 220,000 pounds; no thrust moment.

Figure 4.- Concluded.

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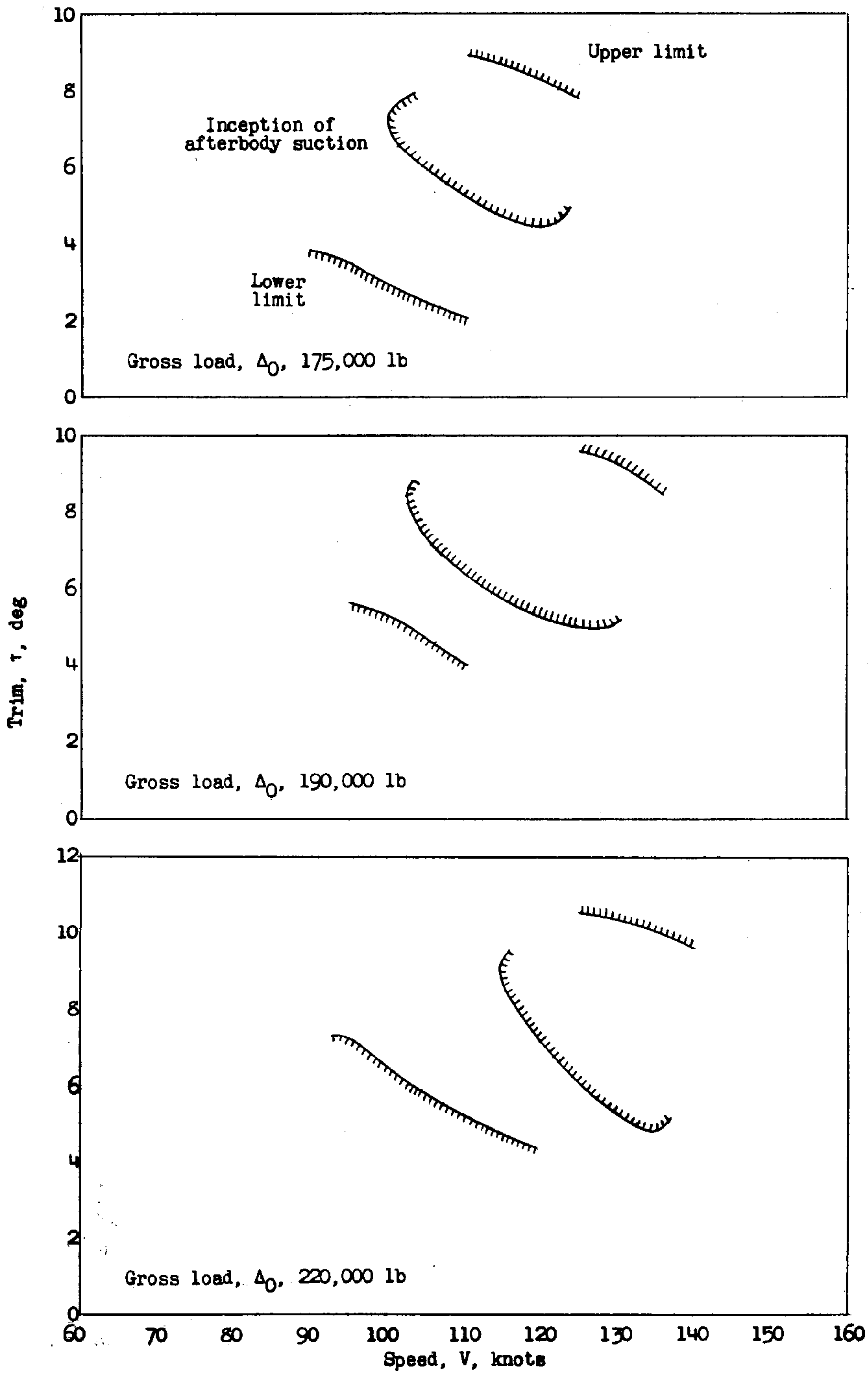
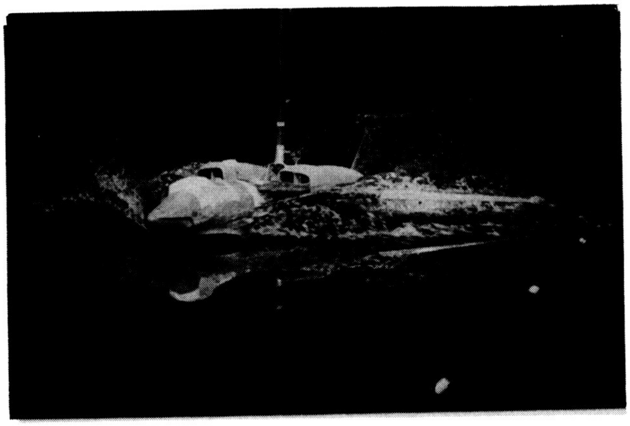
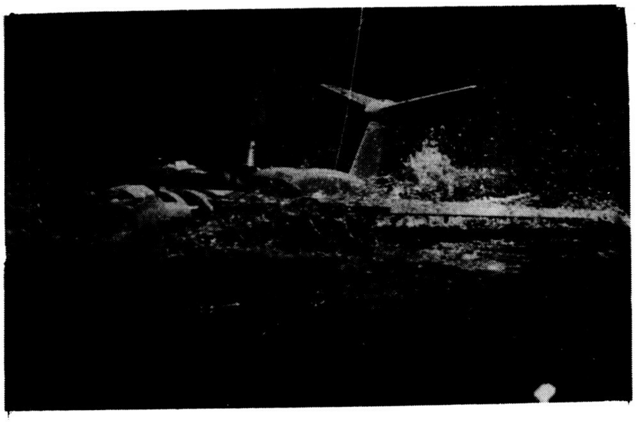


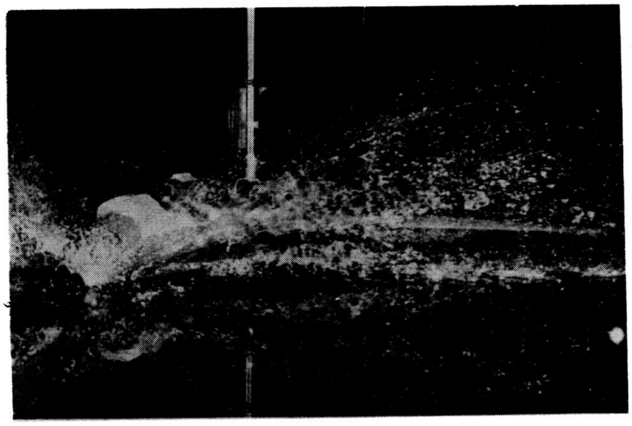
Figure 5 - Trim limits of stability and afterbody suction limits. Basic configuration.



Δ_0 = 160,000 lb
τ = 3.7°
V = 38.4 knots



Δ_0 = 190,000 lb
τ = 3.1°
V = 37.2 knots



Δ_0 = 220,000 lb
τ = 4.8°
V = 43.4 knots

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Figure 6.- Smooth-water spray photographs. Basic configuration.

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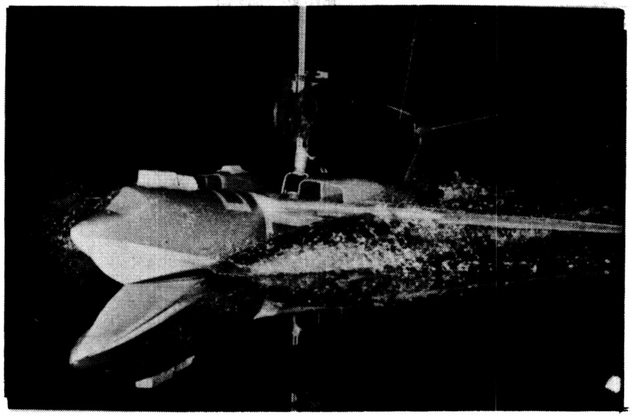
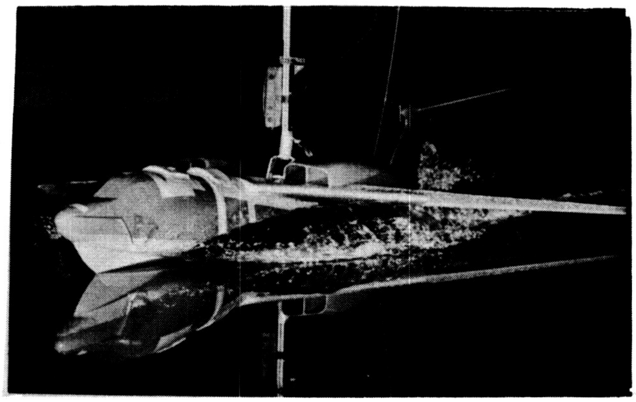
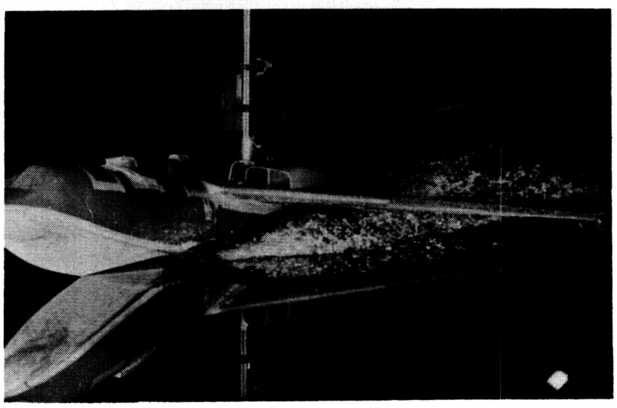


364A
τ = 5.5°
V = 37.6 knots



364C
τ = 5.0°
V = 38.1 knots



364B
τ = 5.1°
V = 38.2 knots

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Figure 7.- Smooth-water spray photographs. Modified forebodies at gross weight of 240,000 pounds.

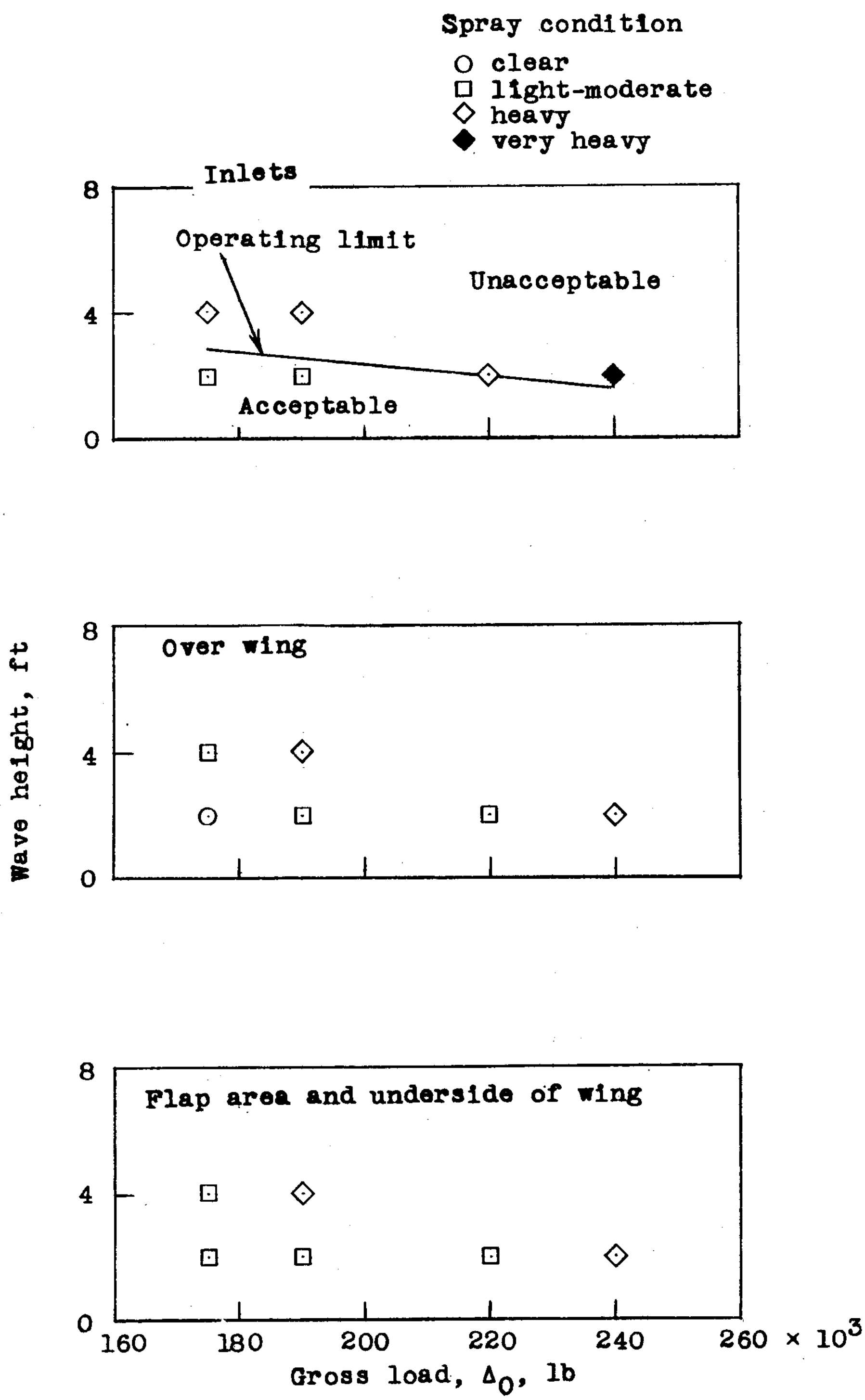
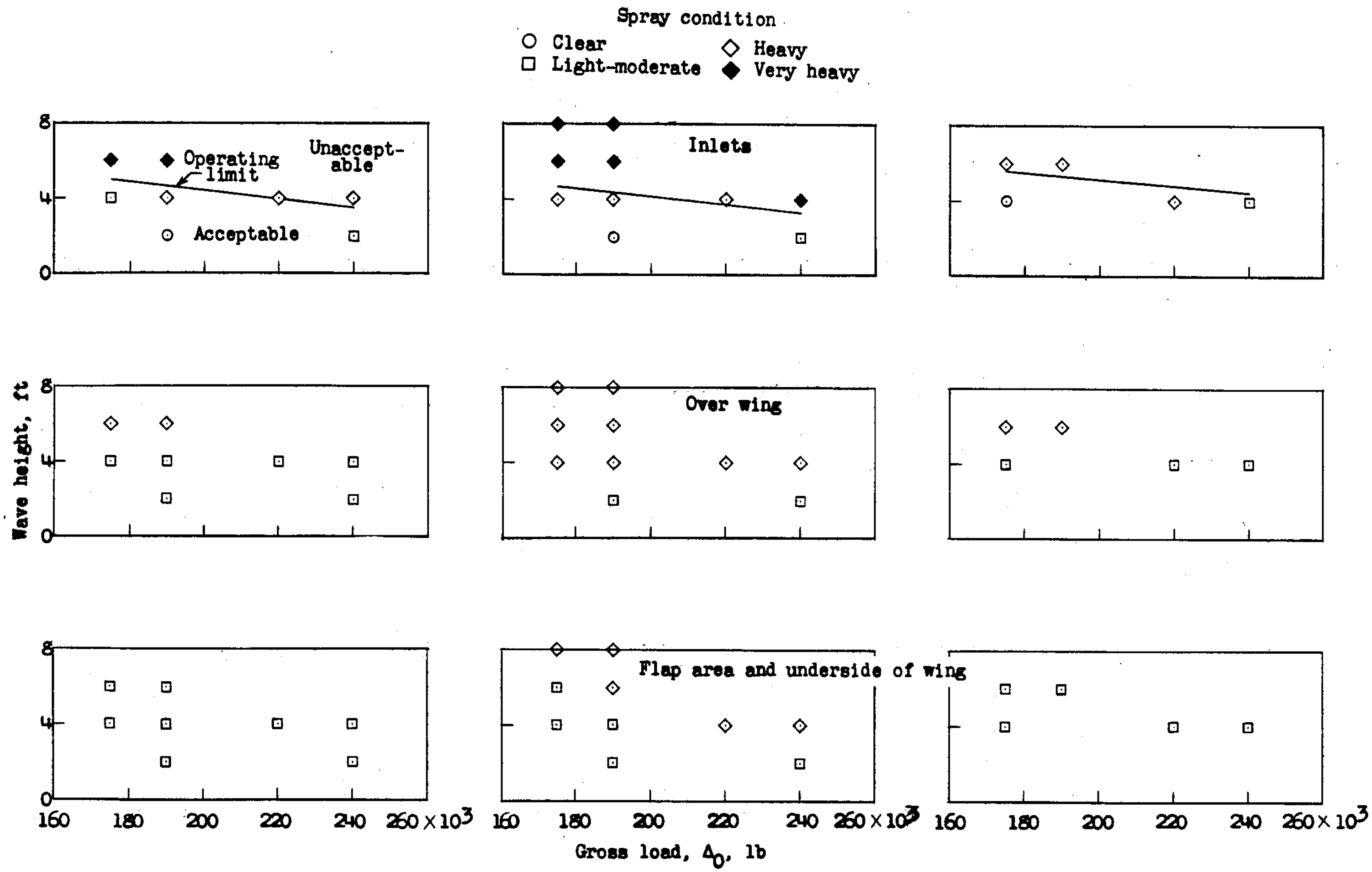


Figure 8.- Variation of rough-water inlet, wing, and flap-spray intensity with wave height and gross load. Basic configuration.



(a) 10-foot extended bow. (b) Basic bow plus 10-foot spacer. (c) 20-foot extended bow.

Figure 9.- Variation of rough-water inlet, wing, and flap-spray intensity with wave height and gross load. Modified forebodies.

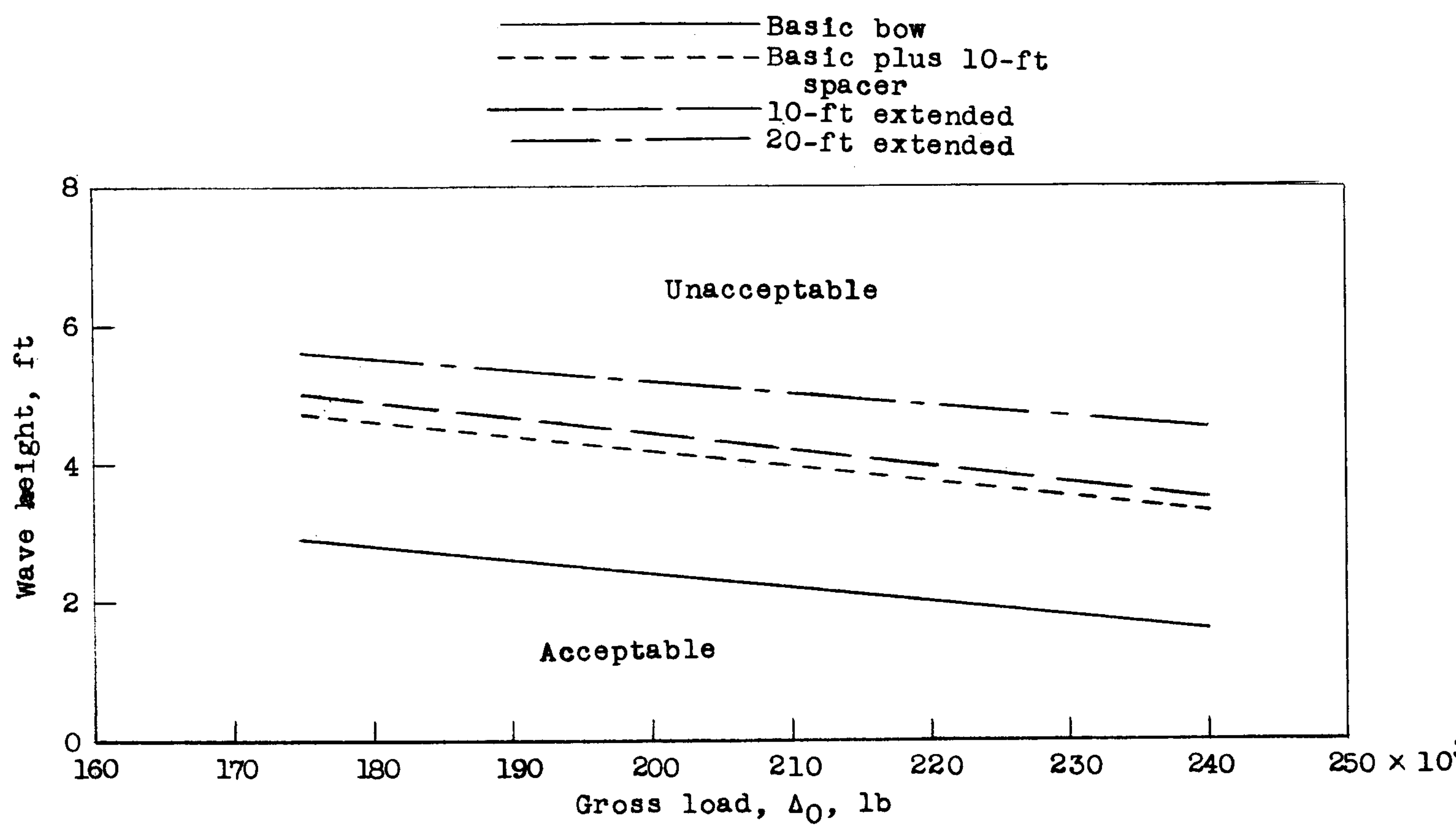


Figure 10.- Comparison of rough-water spray limitations of the basic and modified forebodies.

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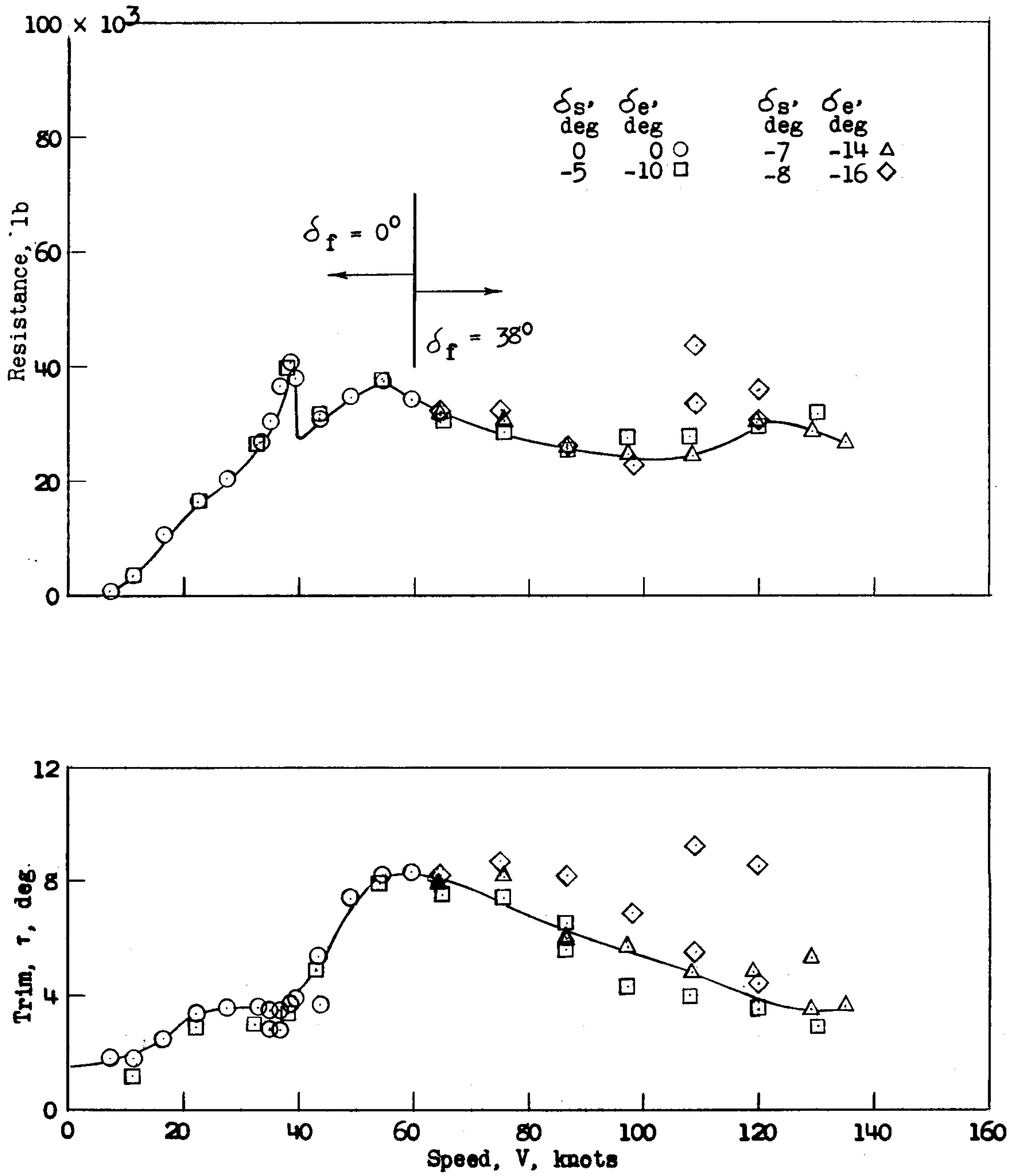
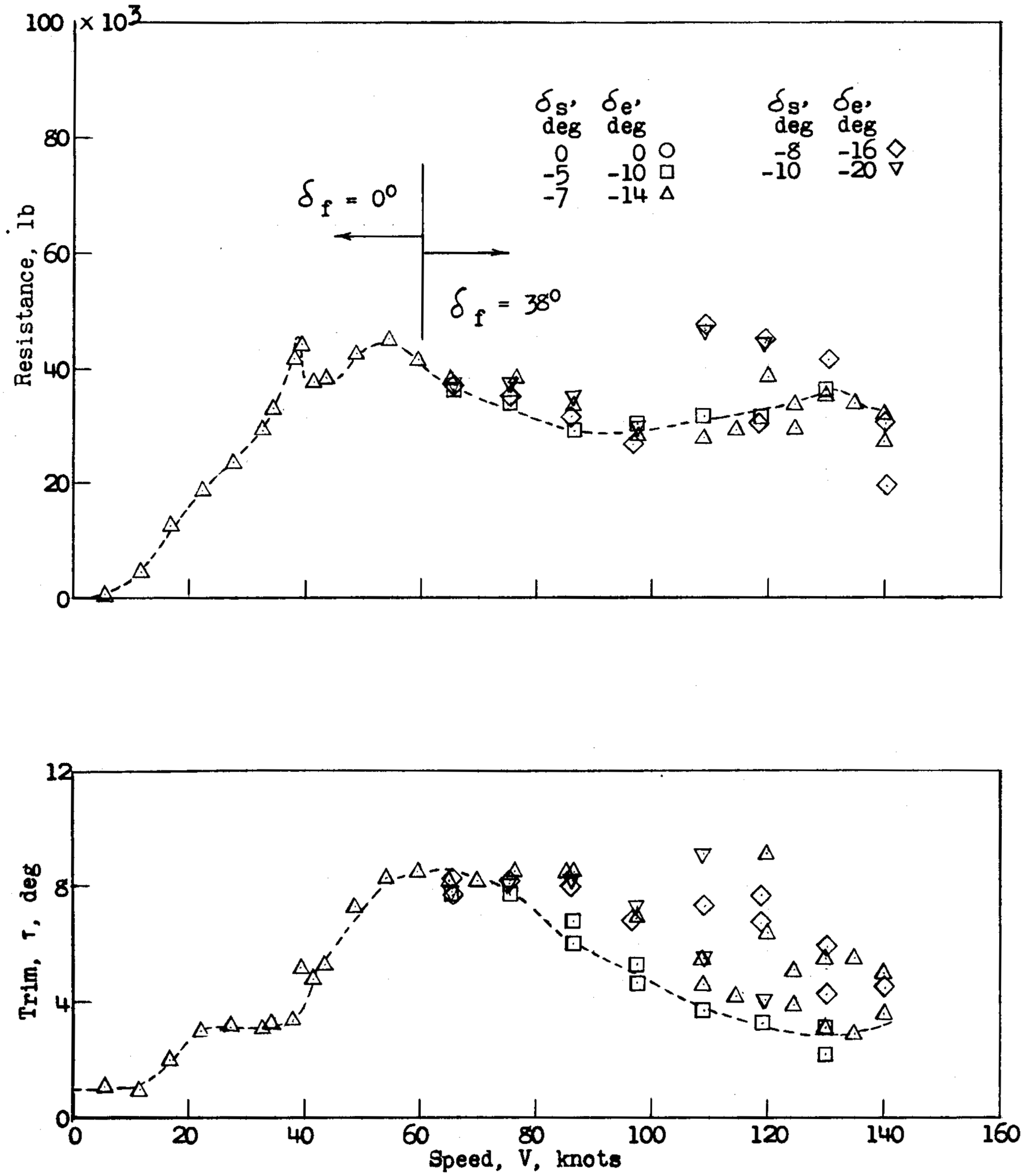


(a) Gross load, 160,000 pounds.

Figure 11.- Variation of smooth-water resistance for best trim and trim with speed. Basic configuration.



(b) Gross load, 175,000 pounds.

Figure 11.- Continued.

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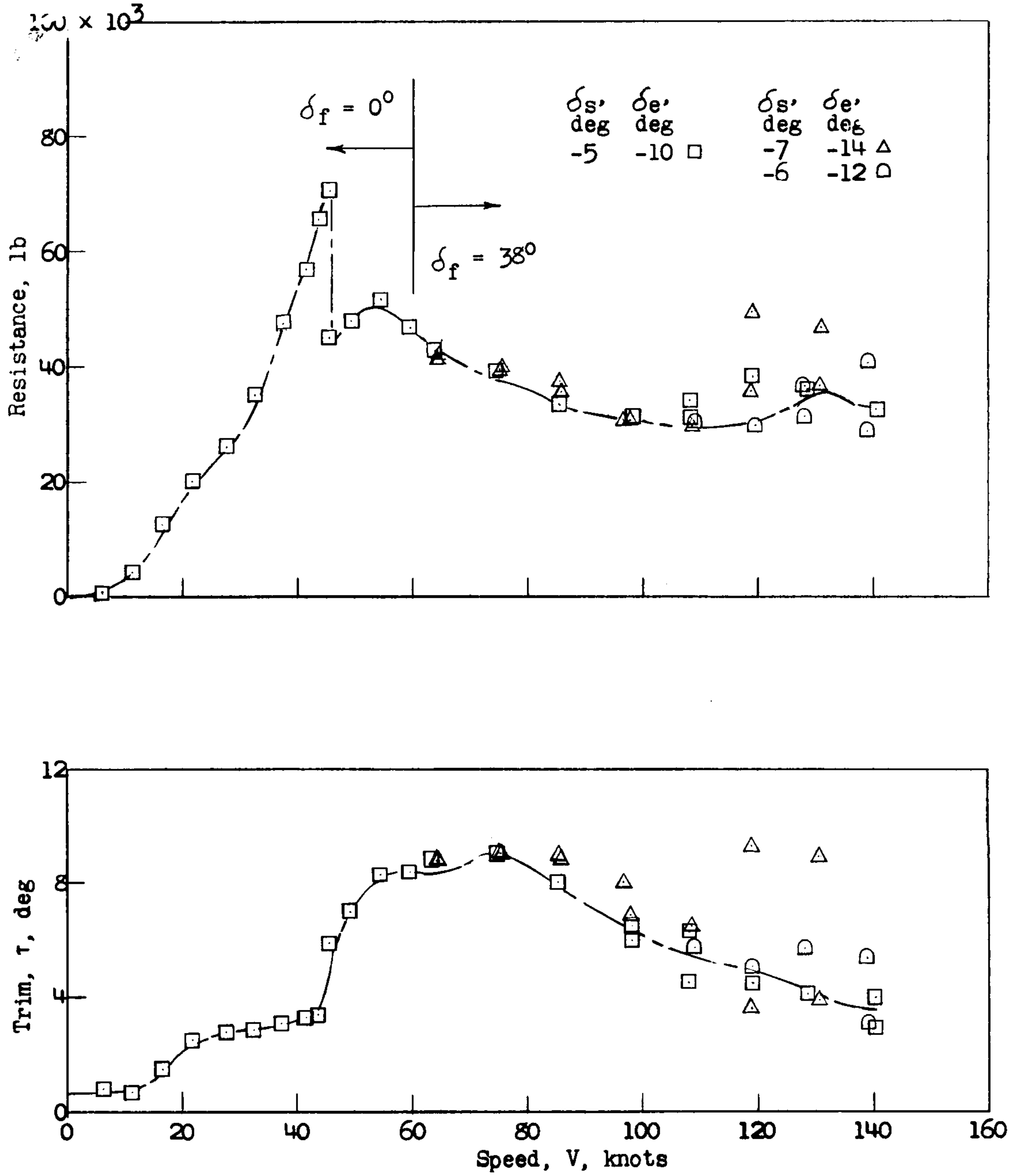
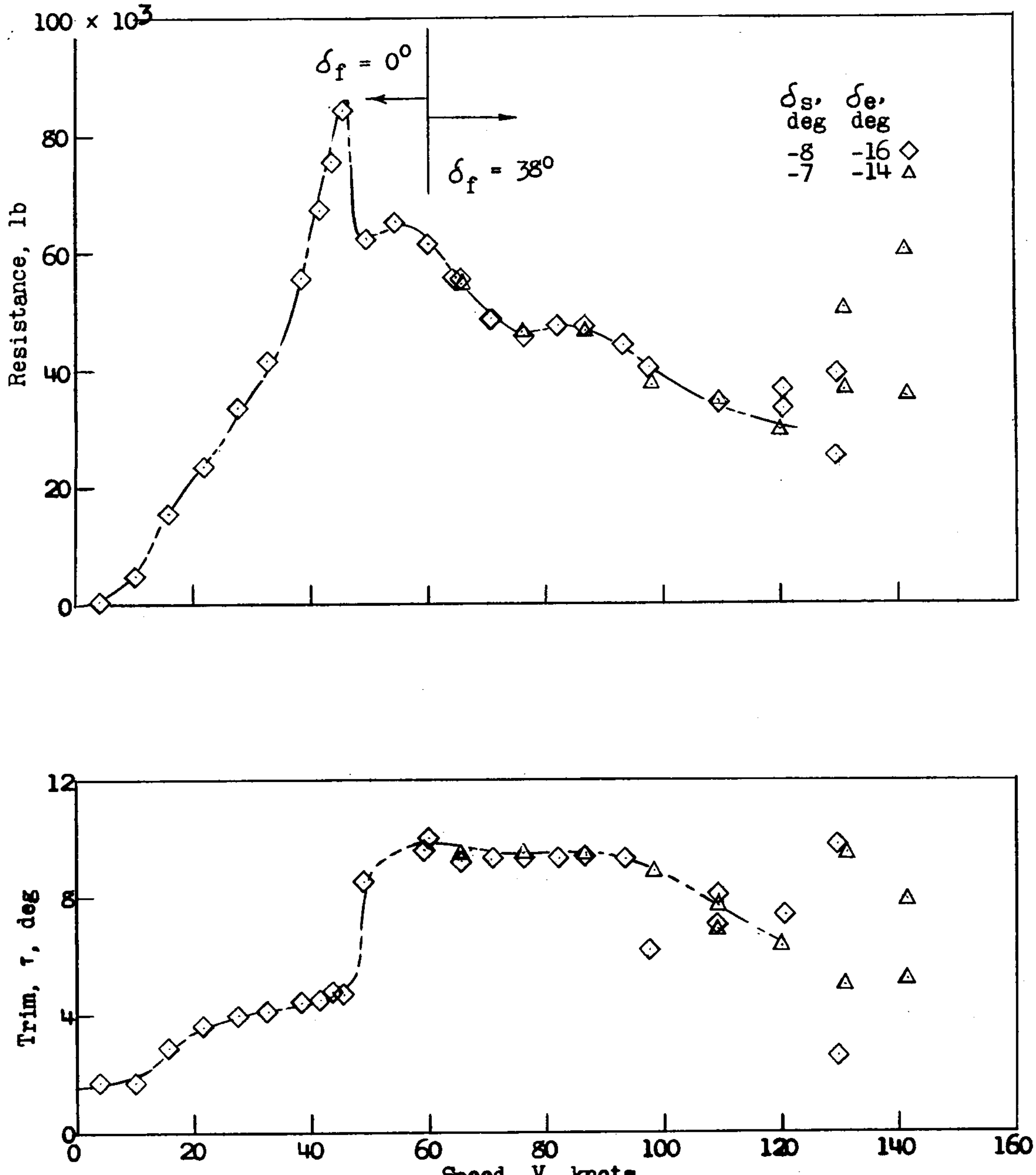


(c) Gross load, 190,000 pounds.

Figure 11.- Continued.



(d) Gross load, 220,000 pounds.

Figure 11.- Concluded.

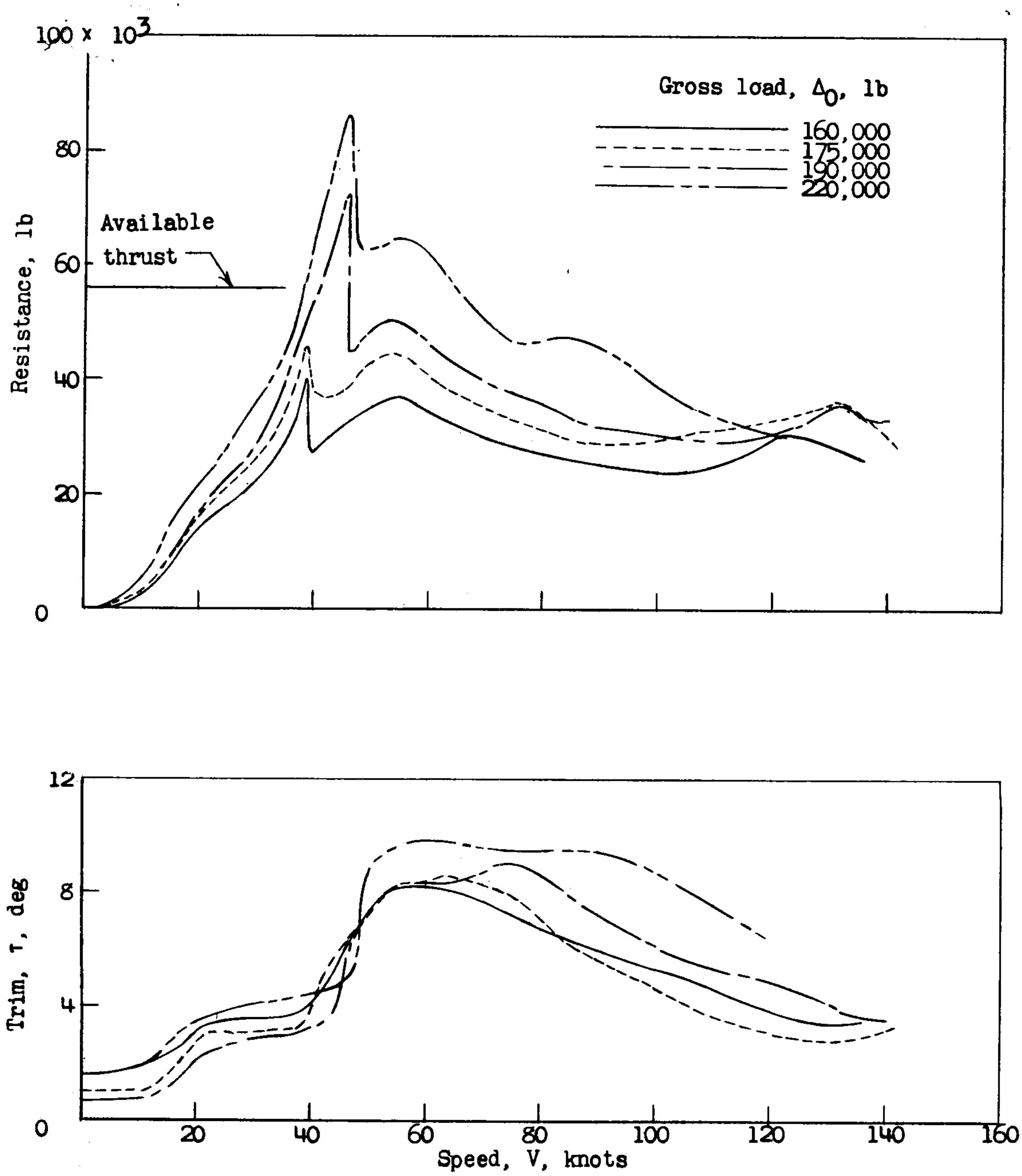
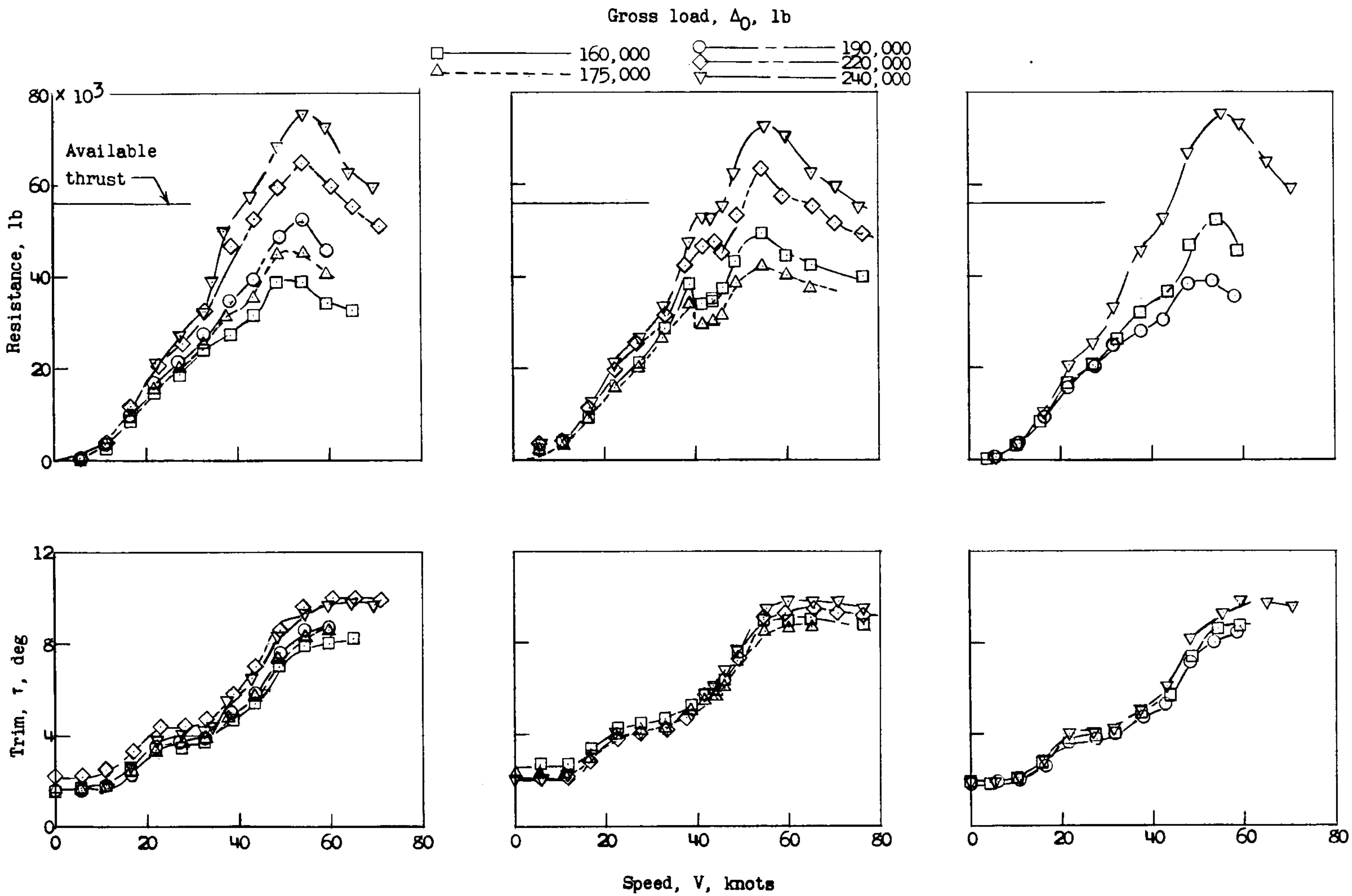


Figure 12.- Summary plot comparing effect of load on the variation of minimum smooth-water resistance for best trim and trim with speed for the basic configuration.



(a) 10-foot extended bow. (b) Basic bow plus 10-foot spacer. (c) 20-foot extended bow.

Figure 13.- Smooth-water resistance and trim tracks. Modified bows.

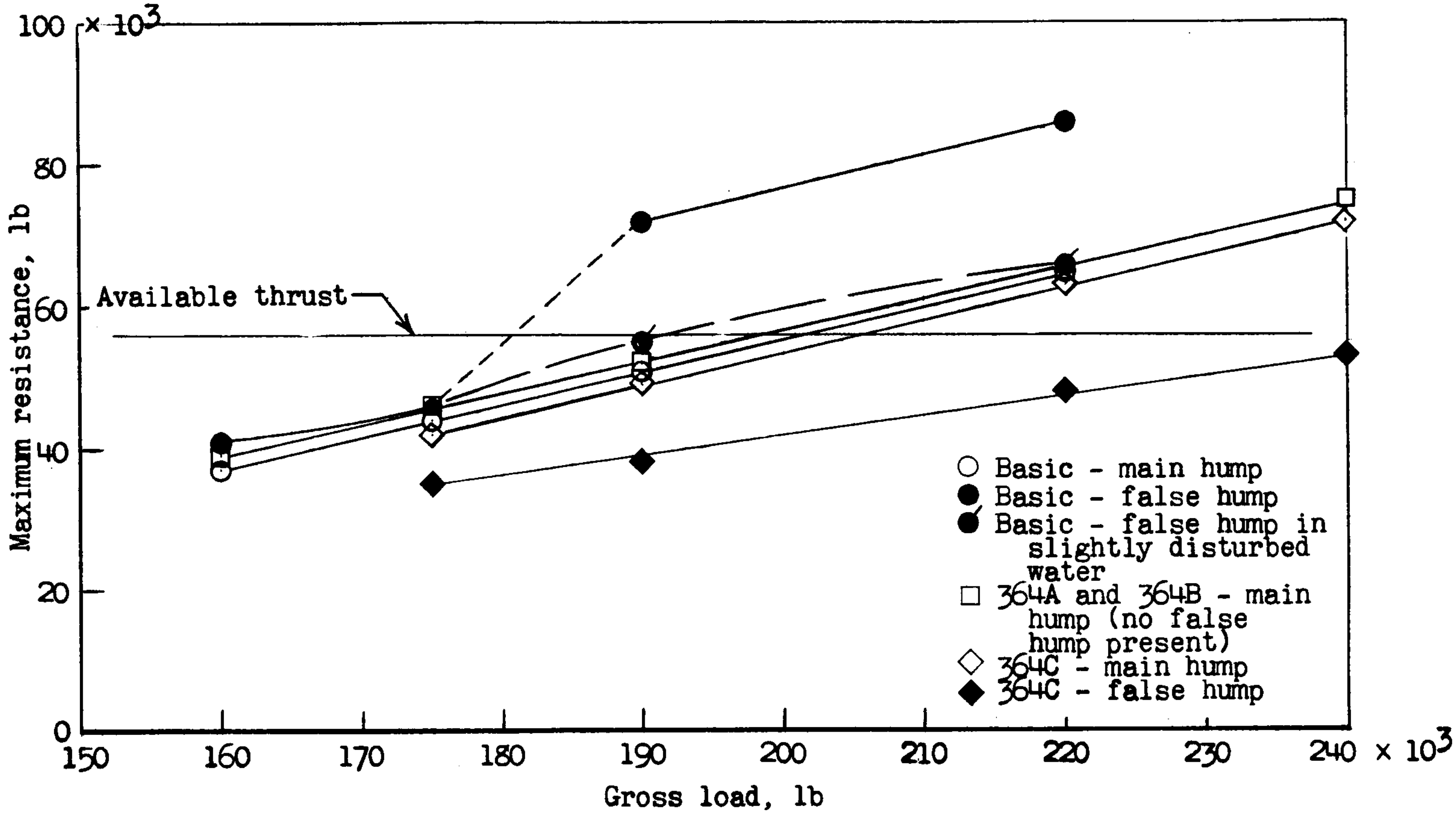
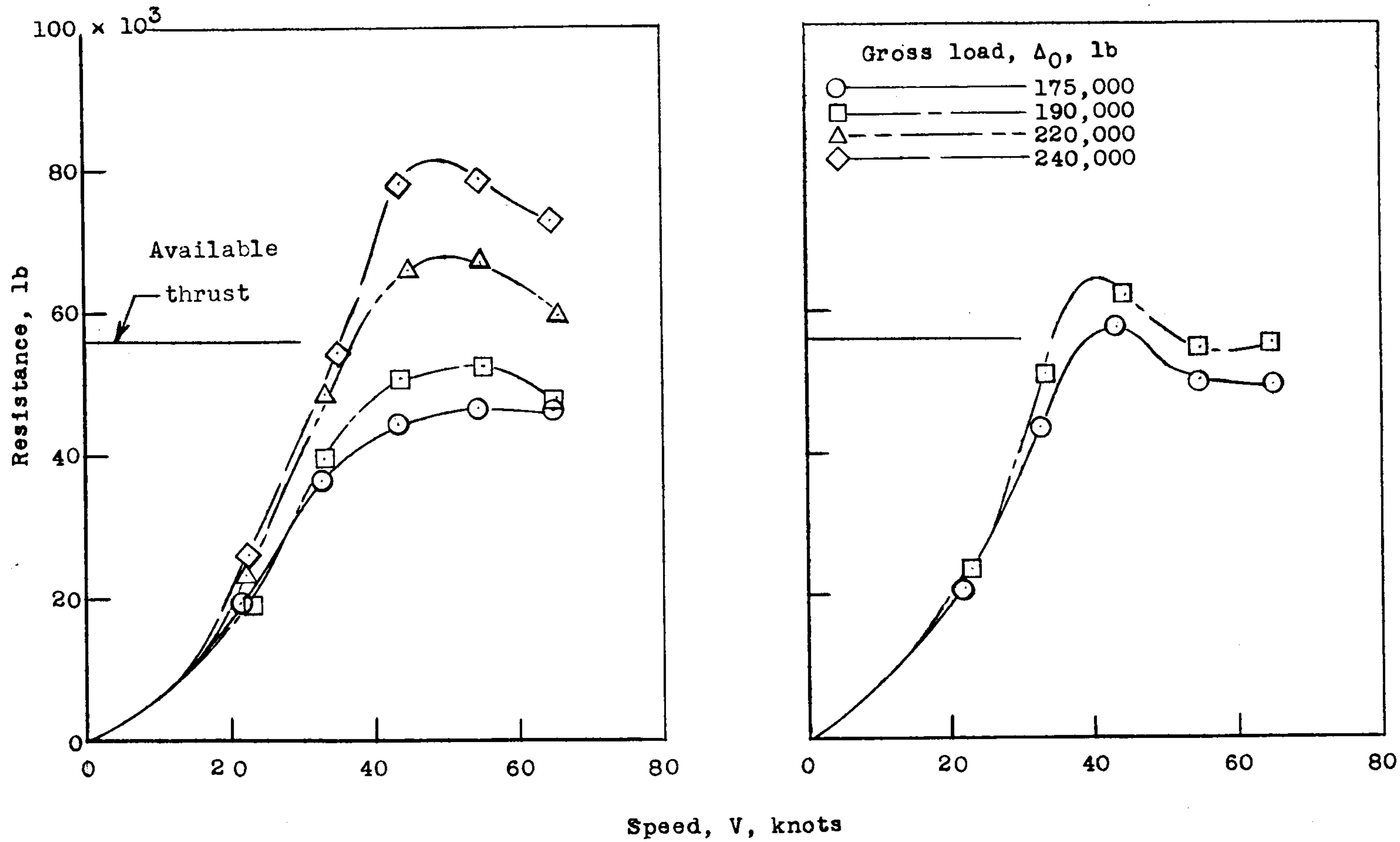


Figure 14.- Smooth-water resistance summary plot. Comparison of all forebodies tested.



(a) 2-foot waves.

(b) 4-foot waves.

Figure 15.- Variation of rough-water resistance with speed in waves 2 and 4 feet high. Basic configuration.

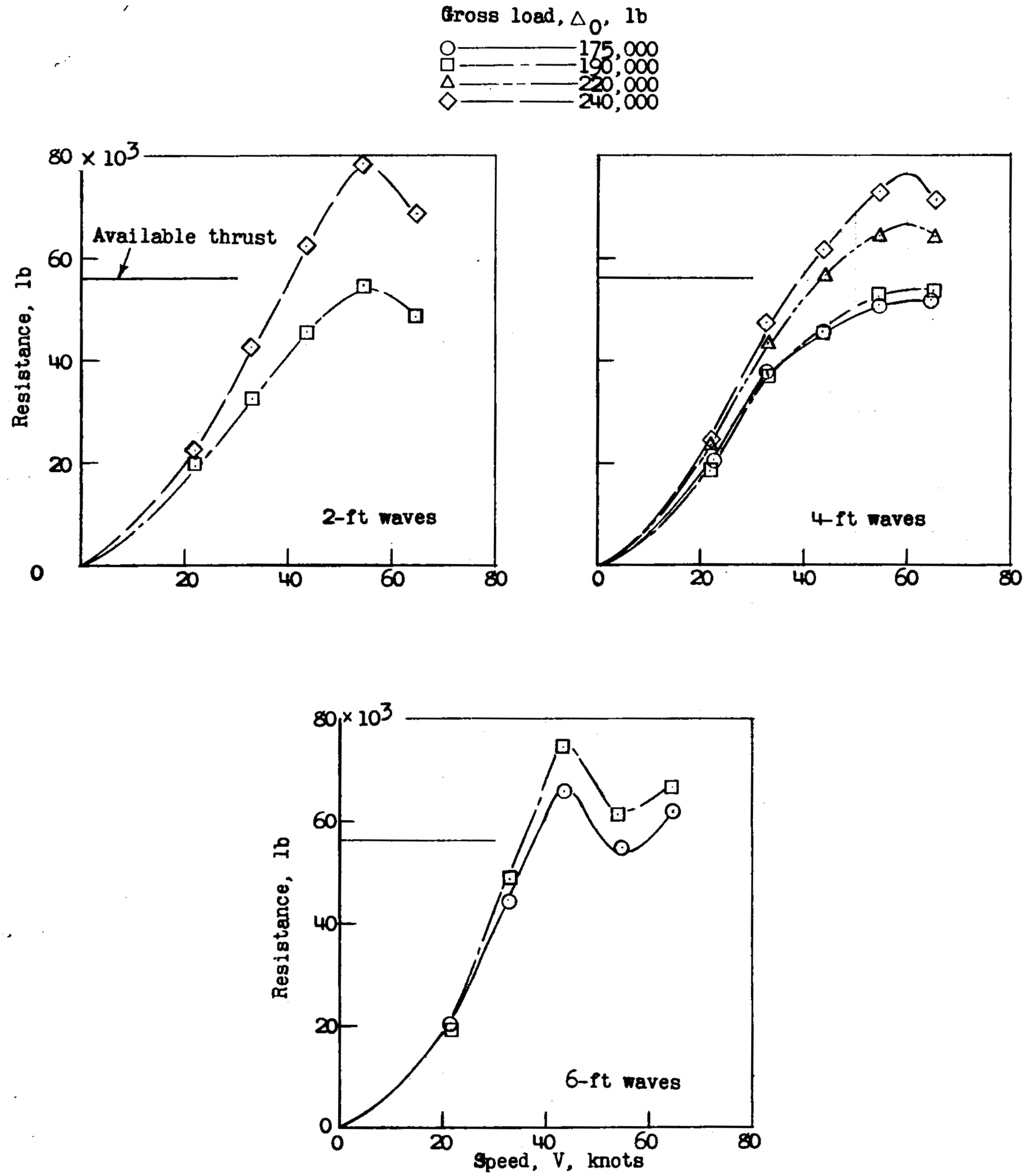


Figure 16.- Variation of rough-water resistance with speed in waves 2, 4, and 6 feet high. 10-foot extended bow.

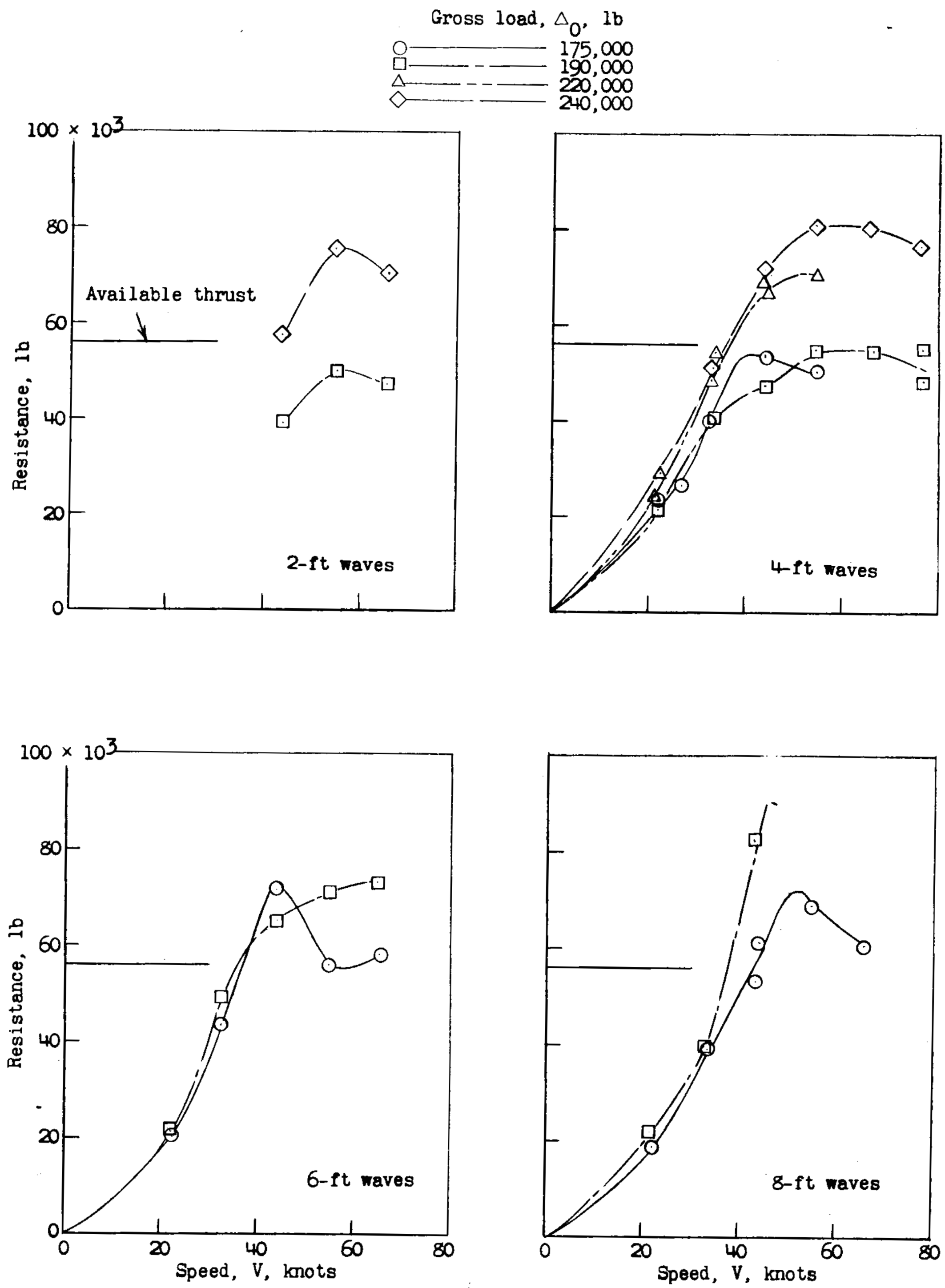


Figure 17.- Variation of rough-water resistance with speed in waves 2, 4, 6, and 8 feet high. Basic bow plus 10-foot spacer.

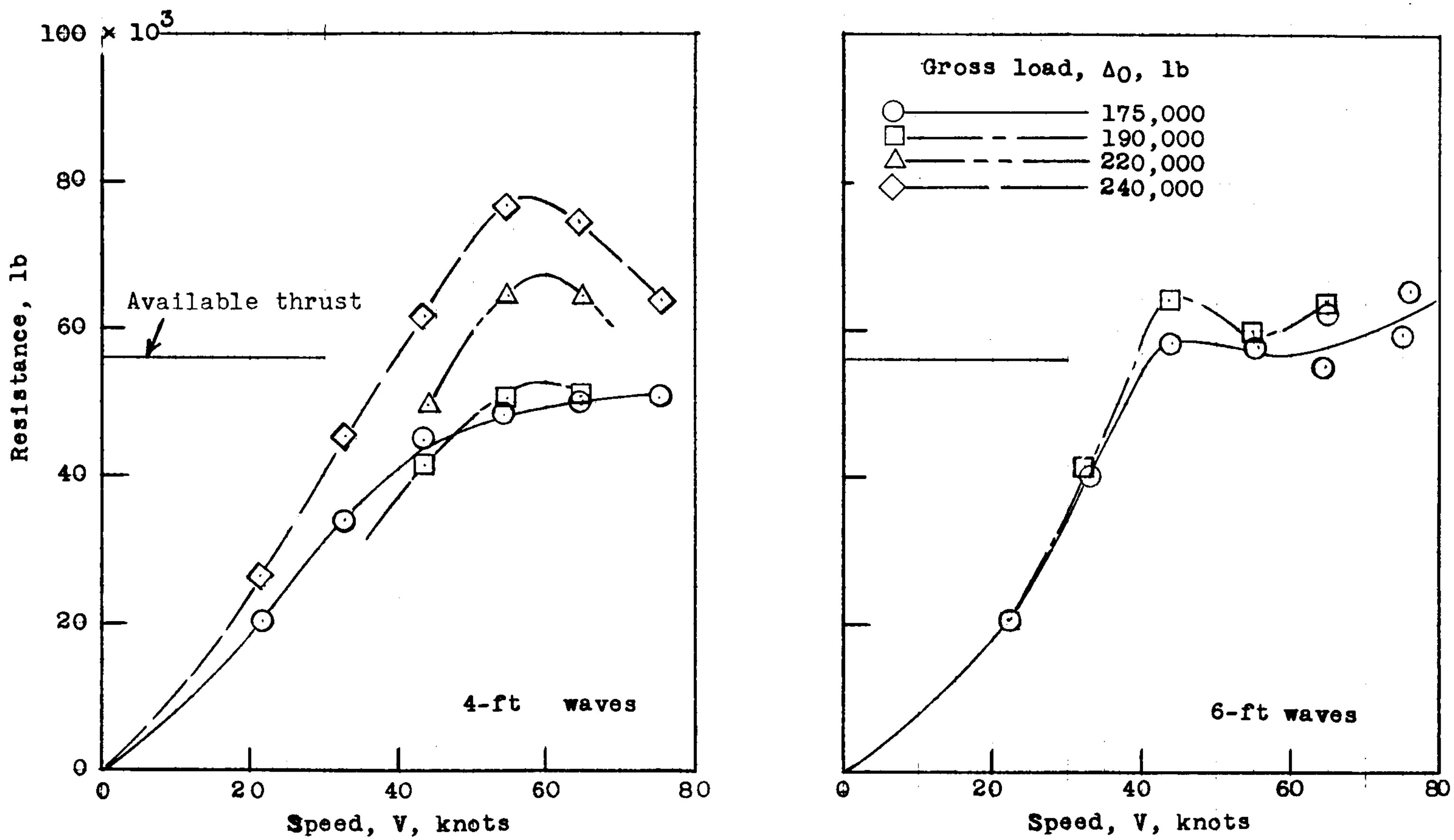


Figure 18.- Variation of rough-water resistance with speed in waves 4 and 6 feet high. 20-foot extended bow.

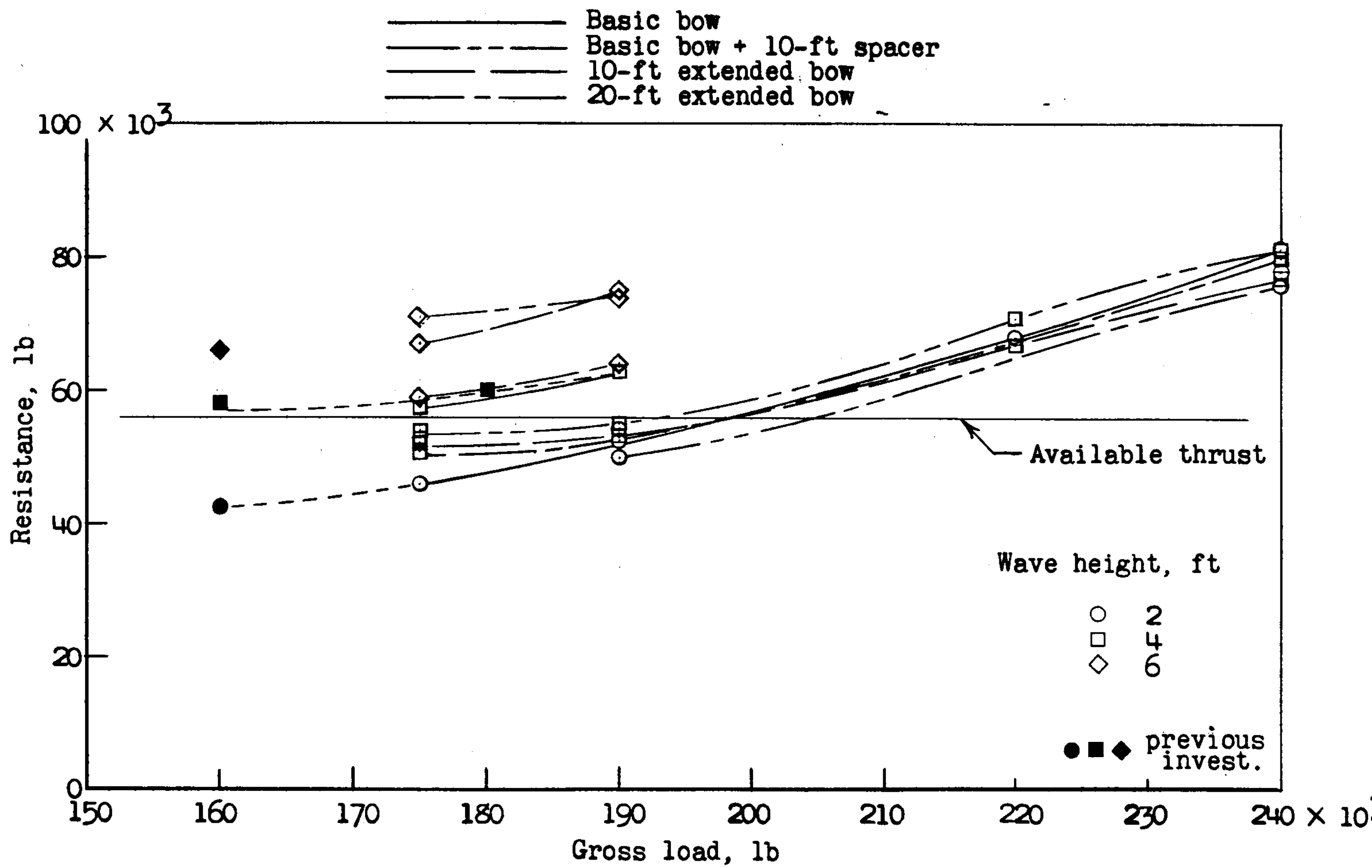


Figure 19.- Variation of main hump resistance with wave height and gross load. Comparison of all configurations tested.